

EF01: Higgs Boson Properties

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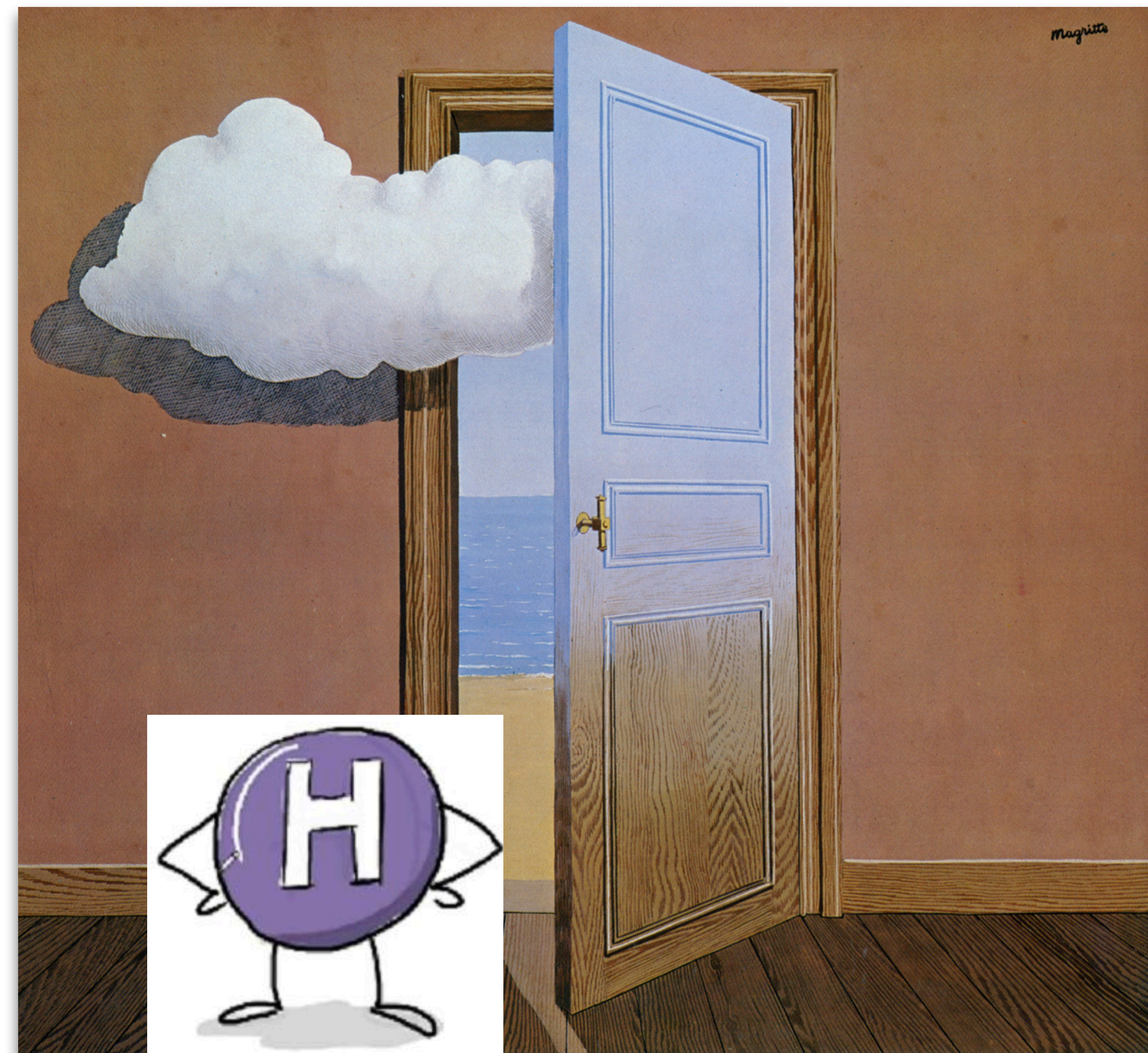
Snowmass21 EF Workshop: Restart

Higgs and the exploration of the EF

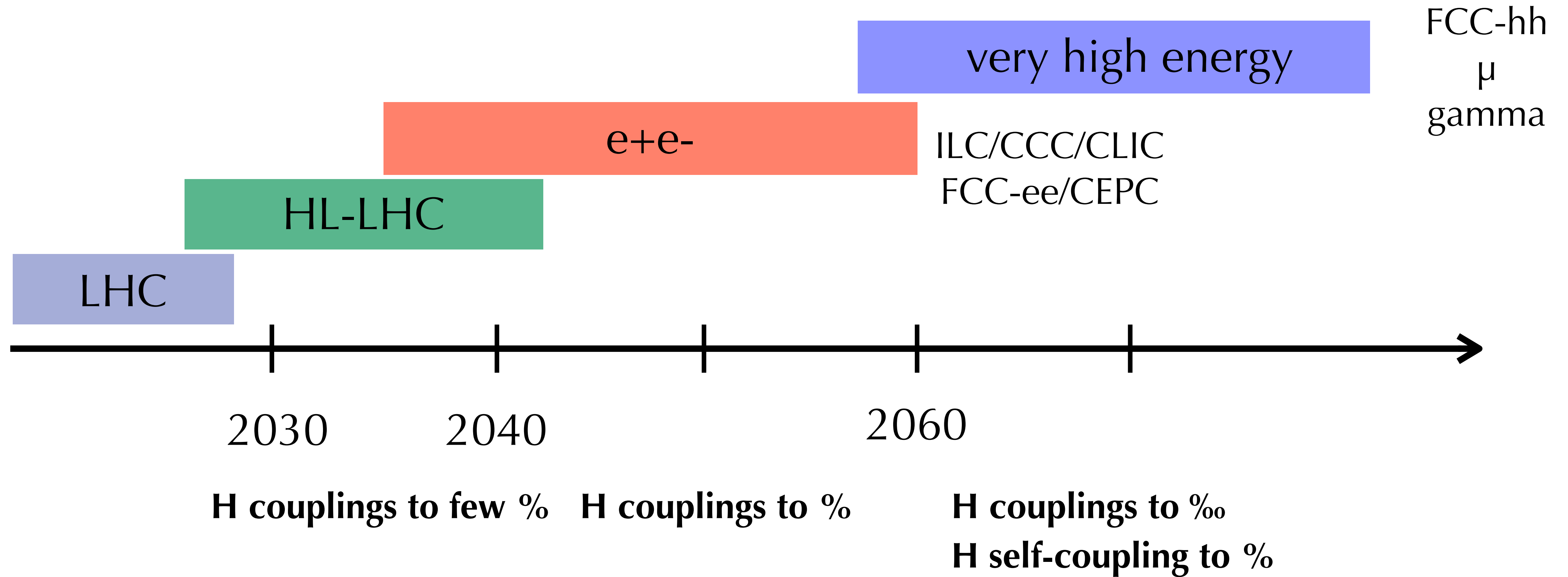
Higgs plays a central element in the future of collider physics

Synergies with other subgroups:

- Higgs Global fits from EF04
- EF01 provides inputs/interpretations
- Searches for new Higgs bosons in EF02, but complementarity with EF01 for interpretation with Higgs measurements



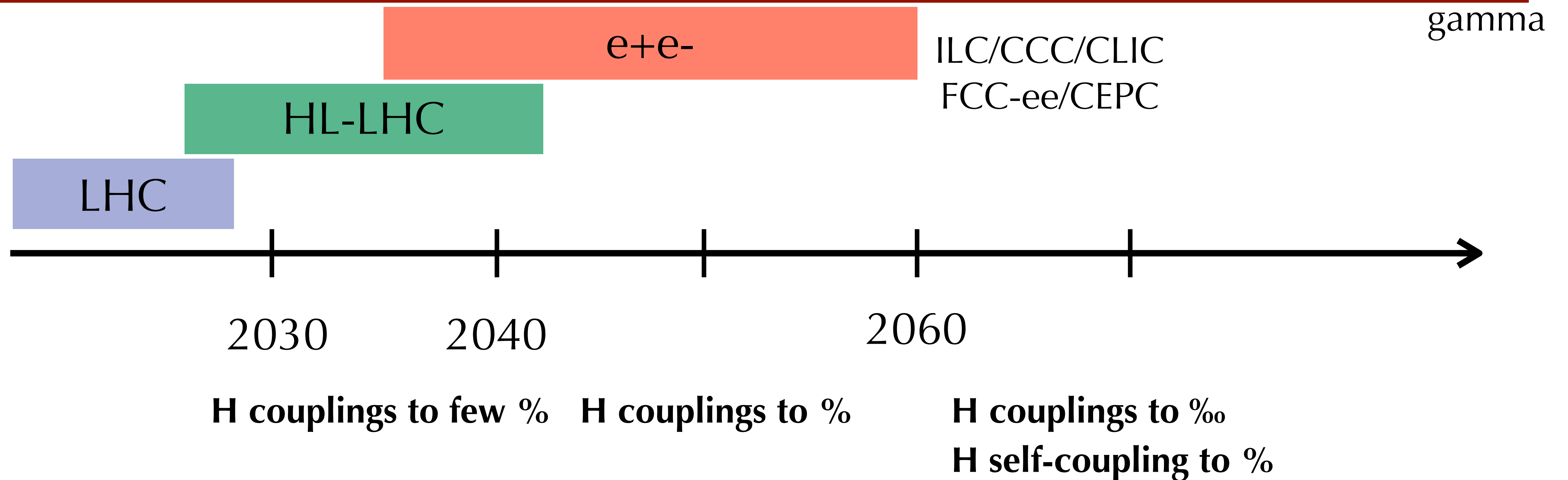
Higgs as a guide



Higgs as a guide

Complementarity between e^+e^- and p-p machines will eventually lead to the most precise understanding of the Higgs couplings

- *In particular, we need to prioritize what we want to learn on top of what HL-LHC will deliver?*
- *Timelines matter.*



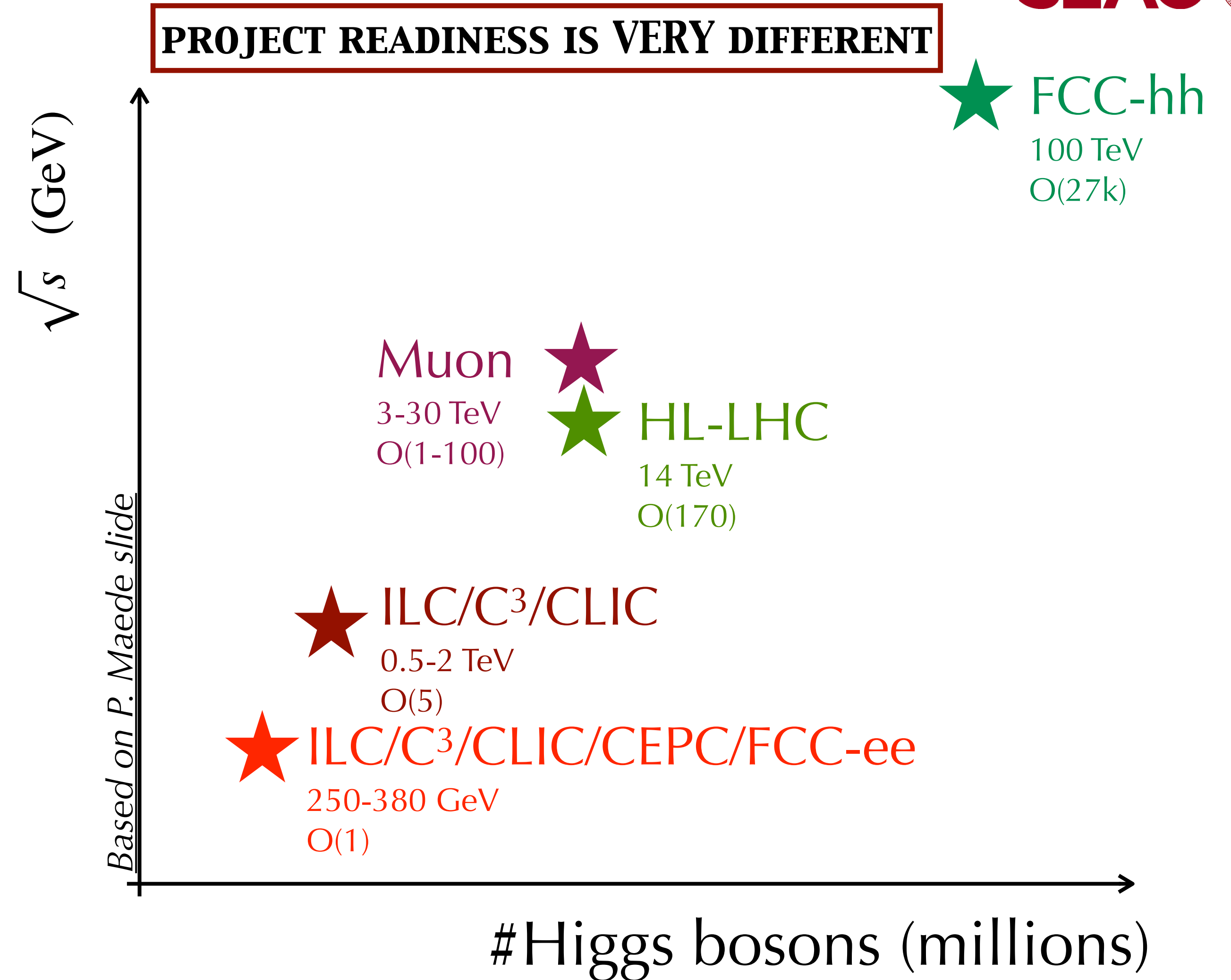
Which collider?

LEPTON COLLIDERS

- **Circular e+e-** (CEPC, FCC-ee)
 - **90-350 GeV**
 - *strongly limited by synchrotron radiation above 350– 400 GeV*
- **Linear e+e-** (ILC, CLIC, C³)
 - **250 GeV — 3TeV**
 - *Reach higher energies, and can use polarized beams*
 - *Relatively low radiation / beam induced backgrounds*
 - *C³ plans is to run at 250/550 GeV*
C3 proposal - talk on Wed
- $\mu+\mu-$
 - **3-30 TeV**

HADRON COLLIDERS

- **75-200 TeV** (FCC-hh)



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PROJECT READINESS IS VERY DIFFERENT

★ FCC-hh
100 TeV
O(27k)

Muon ★
3-30 TeV
O(100k)

We will have to review & harmonize the assumptions on the Higgs studies at future machines for the final reports comparisons

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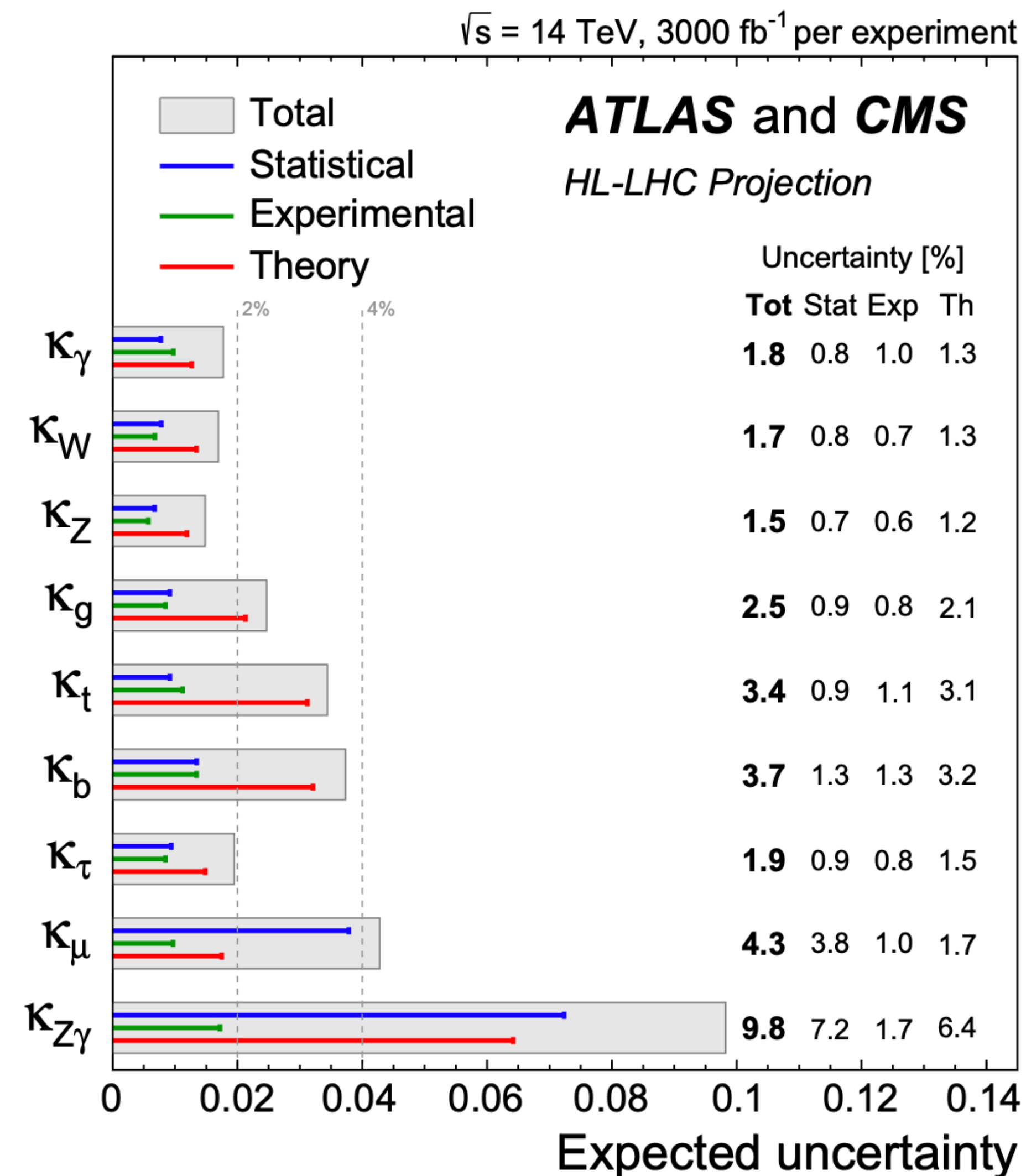
Based on P. M.

★ ILC/C³/CLIC/CEPC/FCC-ee
250-380 GeV
O(1)

#Higgs bosons (millions)

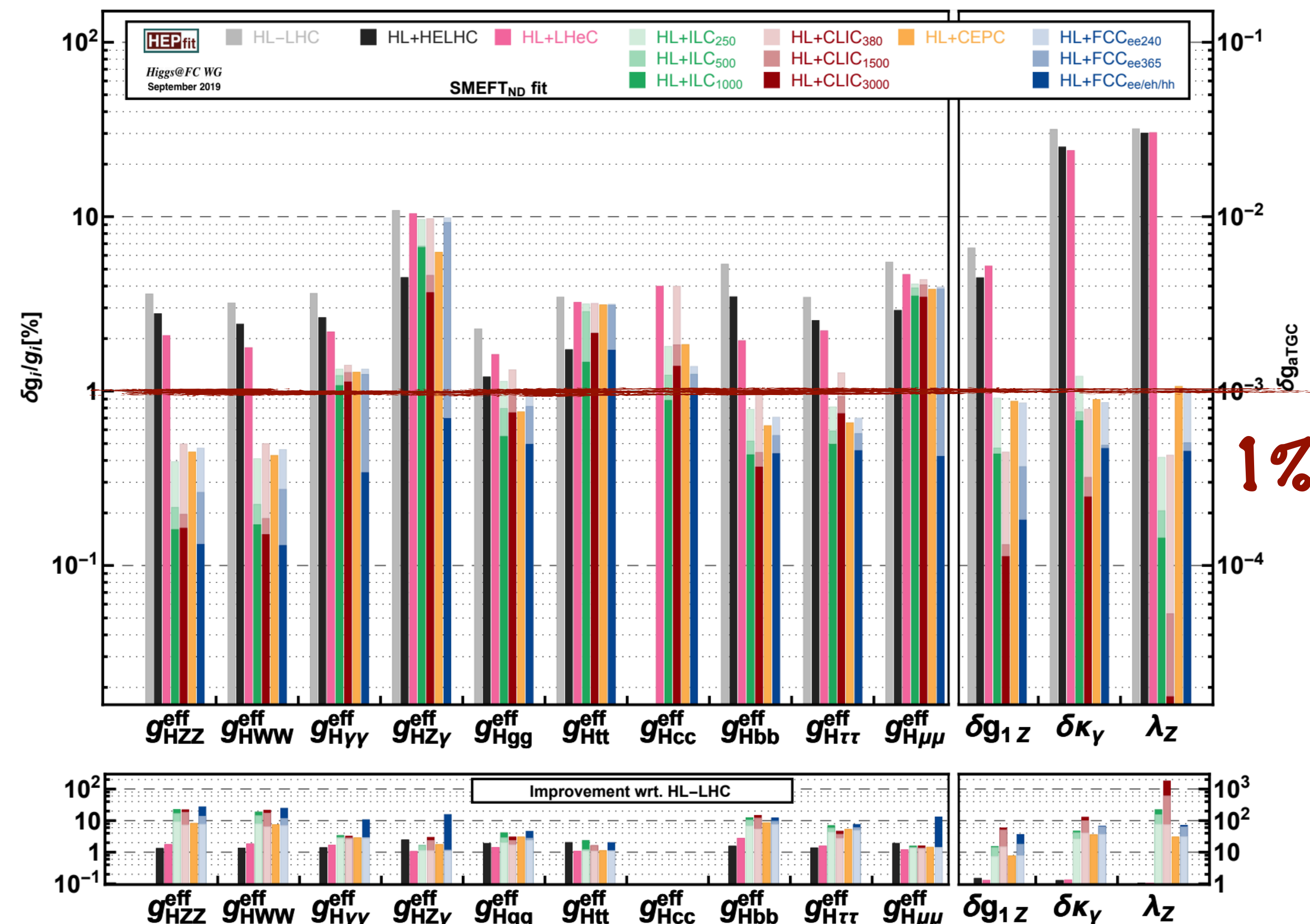
Higgs couplings at future colliders

- Future colliders under consideration will improve with respect to the HL-LHC the understanding of the Higgs boson couplings - 1-5%
 - **Coupling to charm** quark could be measured with an accuracy of $\sim 1\%$ in future e^+e^- machines
 - **Couplings to $\mu/\gamma/Z\gamma$** benefit the most from the large dataset available at HL-LHC and not really improved at future colliders
 - At low energy top-Higgs coupling is not accessible at future lepton colliders
- **Complementarity between HL-LHC and future colliders** (depending on their timeline) **will be the key to explore the Higgs sector**



Higgs couplings at future colliders

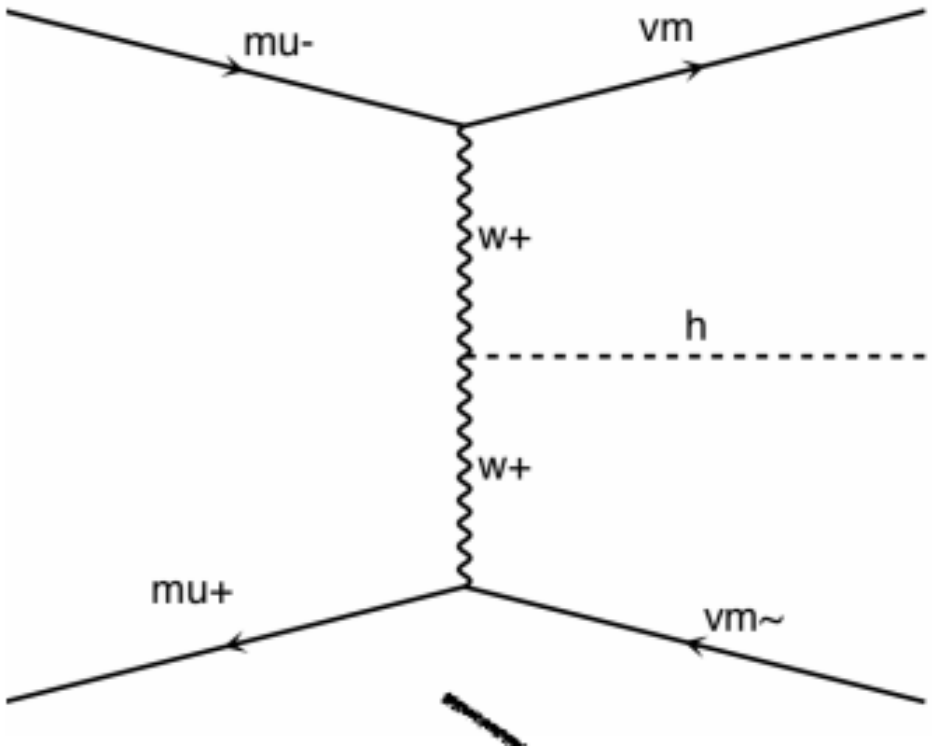
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Higgs couplings at the muon collider

	Fit Result [%]		
	10 TeV Muon Collider	with HL-LHC	with HL-LHC + 250 GeV e^+e^-
κ_W	0.06	0.06	0.06
κ_Z	0.23	0.22	0.10
κ_g	0.15	0.15	0.15
κ_γ	0.64	0.57	0.57
$\kappa_{Z\gamma}$	1.0	1.0	0.97
κ_c	0.89	0.89	0.79
κ_t	6.0	2.8	2.8
κ_b	0.16	0.16	0.15
κ_μ	2.0	1.8	1.8
κ_τ	0.31	0.30	0.27

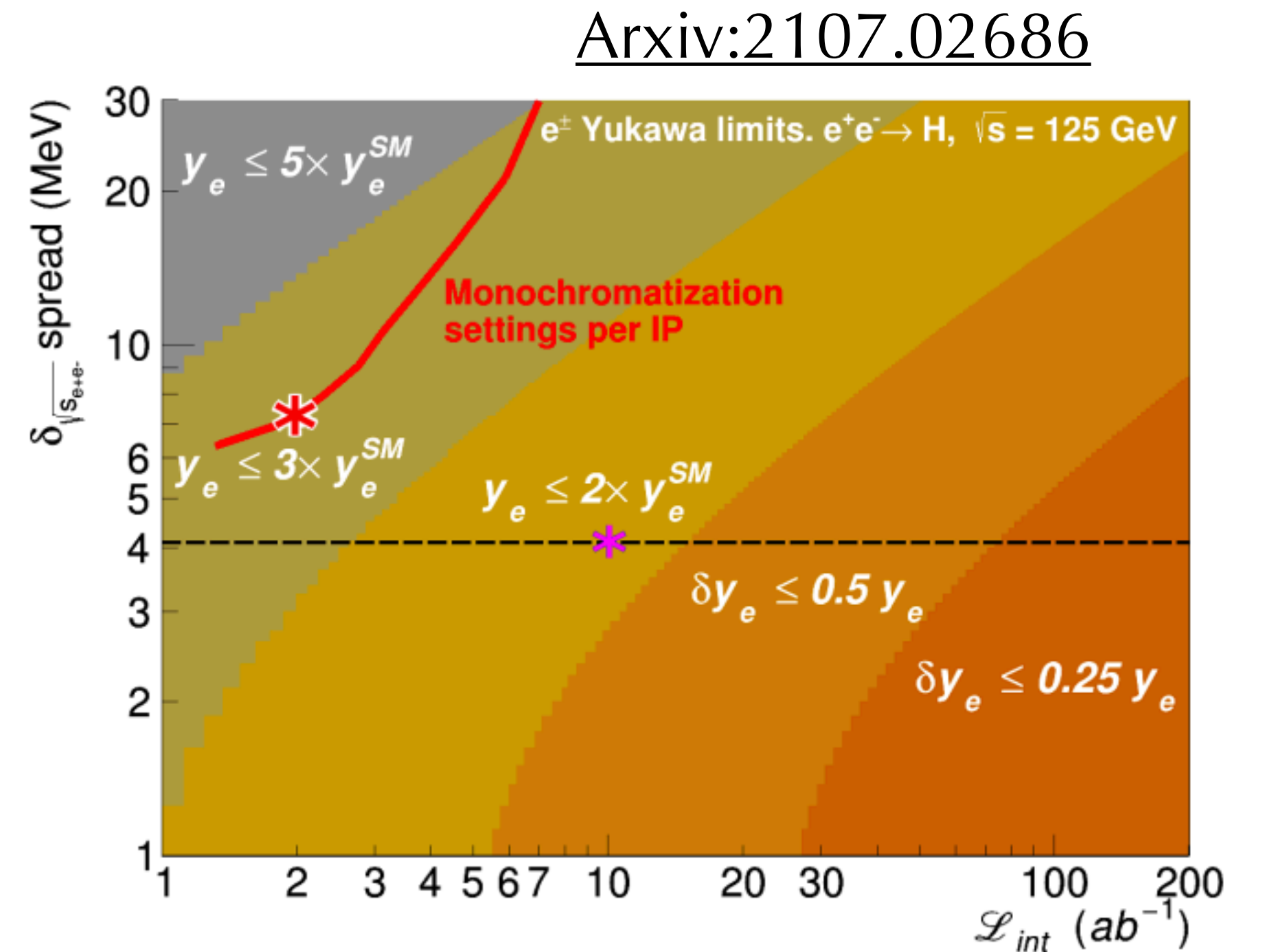
Higgs Updates at MuC EF Workshop EF01-02 Zhen Liu 09/01/2021



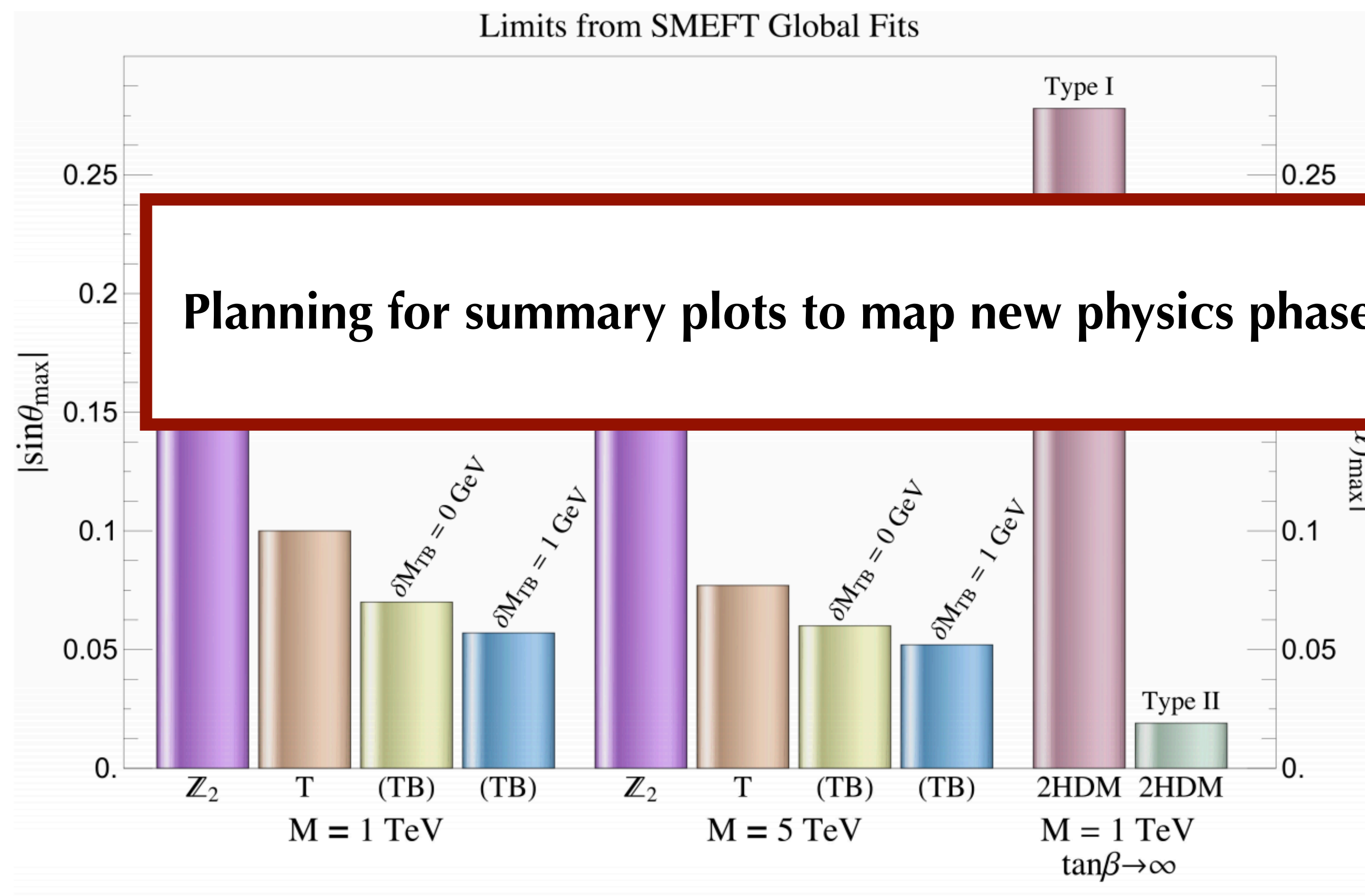
Zhen Liu

67 LOIs submitted to EF01 covering several topics:

- Progress on understanding light fermion Yukawa couplings
 - **Electron** Yukawa at FCC-ee with 4 years running, $Y_e < 1.6 Y_e^{SM}$
 - **Strange** Yukawa
 - **Charm** Yukawa limit, $|\kappa_c| < 8.5$ (CMS) motivates new studies
 - Higgs production at high momentum and HH production could provide constraints at pp machines (C. Grojean, L. Alasfar)
- Searches for flavor violating H couplings motivated by LHC limits on $H \rightarrow \mu e$, $H \rightarrow \mu \tau$ and by B flavor anomalies
- Progress on CP violation - expected an update of the 2013 study
 - Goal is to sharpen theoretical expectations / models
 - Connect to broader EFT and distinguish between linear and quadratic effects in the observables (A. Gritsan)



- Progress on how to map BSM models to SMEFT constraints (S. Homiller, A. Greljo)
- Include complete 1-loop matching for other models, more NLO effects in fits, and more distributions



Integrate out new particles at matching scale ($M \sim \text{few TeV}$)

Evolve Coefficients down to EW scale

Fit to Higgs + Diboson + EWPO Data
 → Limits on physical parameters!

The Higgs self-coupling at future colliders

arXiv:1910.00012

arXiv:2004.03505



- We expect an update on the HL-LHC projections
 - Full Run 2 results are being published approaching the SM limits on the self-coupling
 - YR HL-LHC estimate was based on projections from early data analyses
- **Muon collider** 25% (6%) at 3 (10) TeV Zhen Liu's talk

	collider	single- H	HH	combined
●	HL-LHC	100-200%	50%	50%
	CEPC ₂₄₀	49%	—	49%
	ILC ₂₅₀	49%	—	49%
●	ILC ₅₀₀	38%	27%	22%
●	ILC ₁₀₀₀	36%	10%	10%
	CLIC ₃₈₀	50%	—	50%
	CLIC ₁₅₀₀	49%	36%	29%
●	CLIC ₃₀₀₀	49%	9%	9%
	FCC-ee	33%	—	33%
●	FCC-ee (4 IPs)	24%	—	24%
	HE-LHC	-	15%	15%
●	* FCC-hh	-	5%	5%

* arXiv:2004.03505 2.9-5.5%
depending on the systematic assumptions

These values are combined with an independent determination of the self-coupling with uncertainty 50% from the HL-LHC.

Which precision on the self-coupling is needed?

arXiv:1910.00012



Bronze 100%



Silver 25–50%



Gold 5–10%



Platinum 1%

Sensitivity to:

models where we expect new particles of few hundred GeV mass

mixing of the Higgs boson with a heavy scalar with a mass of order 1 TeV

loop diagram effects created by any new particle with strong coupling to the H

typical quantum corrections to the Higgs self-coupling generated by loop diagrams

Which precision on the self-coupling is needed?

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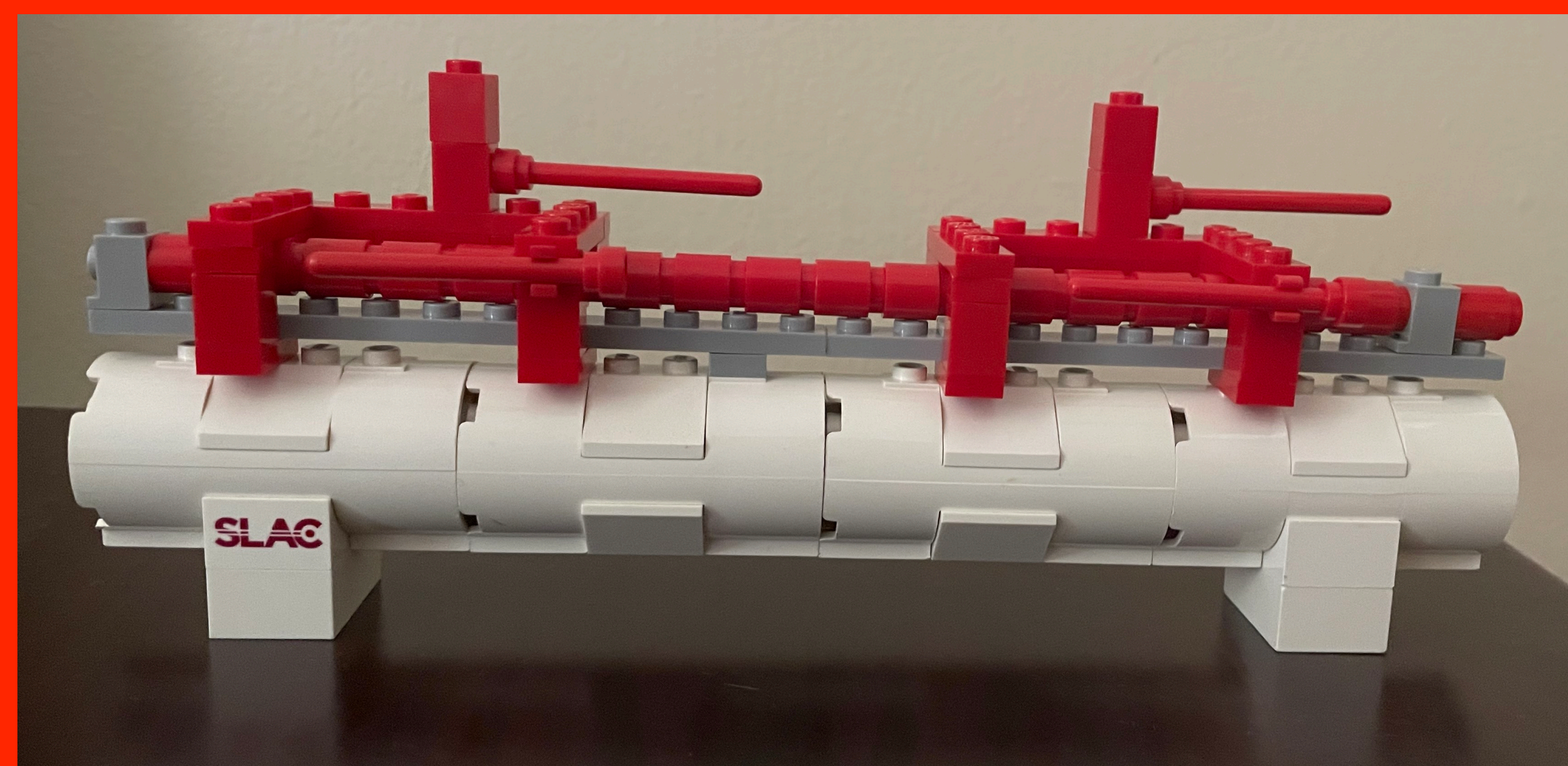
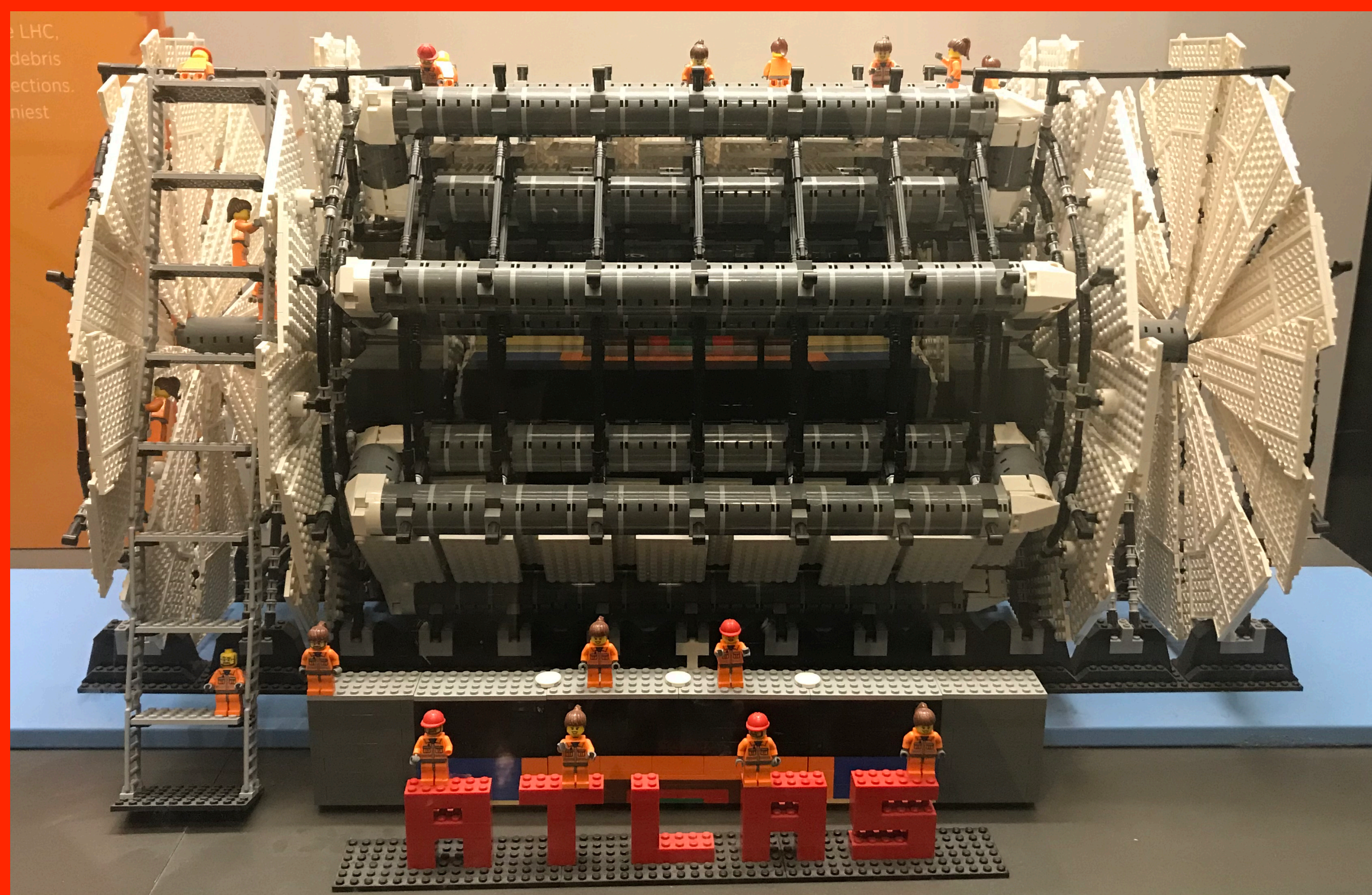
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Planning to define new physics benchmarks for resonant and non-resonant HH that we could use for interpretations as the precision on the self-coupling improves

typical quantum corrections to the Higgs self-coupling generated by loop diagrams

- **Which physics beyond the Standard Model can be probed by precision measurements of Higgs couplings?**
 - How precise do these measurements need to be in order to probe BSM physics scenarios?
 - How are direct searches for new Higgs-like particles complementary to precision Higgs coupling measurements
 - This should be study by exploring the complementarity between HL-LHC and future colliders (accounting for their different timelines).
- Does the Higgs boson result from the scalar potential of the Standard Model?
 - How can measurements of double Higgs boson production be improved to better probe the potential ?
 - Which is the target precision for this? - taking into account the correlations with the other Higgs measurements
- How can measurements in the Higgs sector be combined with measurements in other sectors to improve our understanding of high scale physics?
- What theory calculations are needed to enable the theory precision to match the projected experimental precision of future measurements?

- Higgs couplings (from the ESG)
 - Include updated list of machines and their parameters
 - Re-visit some of the assumptions (i.e. flavor..)
 - Hopefully new results from EF04
- Some example maps of new physics phase space to constraints on EFT operators
- New physics benchmarks for resonant and non-resonant HH that we could use for interpretations as the precision on the self-coupling improves
- Upcoming discussions:
 - Sept 15 meeting 12-2 EDT
 - Higgs parallel at Higgs 2021
 - Plans to survey of ongoing efforts in November



Extra

- **We will be working closely together with EF04 within the SMEFT framework:**
 - Estimate EFT uncertainties (NLO, dim-8 effects, linear vs quadratic...), new physics in backgrounds, theoretical constraints (positivity, analyticity)
 - More combined Higgs and top analysis
 1. effects of top dipoles or 4 fermion ops. with tops
 2. constraints on top EW couplings from their NLO effects in Higgs and diboson processes (particularly relevant for low-energy colliders below ttH threshold)
 - Include differential observables
 - Explore more flavor scenarios (and make connection with flavor data)
- SMEFT is a baseline, how we account for specific assumptions and model-dependency?
- Complementarity with new physics searches